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A New Binary Inductive Divider Comparator System for Measuring High-Voltage Thermal Converters

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Abstract* - National Measurement Institutes have traditionally used bootstrapping or build-up techniques to determine the ac-dc difference of high-voltage thermal converters (HVTCs) in terms of the ac-dc difference of lower-voltage converters. We describe a method of determining the ac-dc difference of HVTCs that is independent of the build-up process. A description of the system and technique is given, and preliminary data are presented.

***Keywords:* ac-dc difference, high-voltage TVC, inductive divider, thermal voltage converter, thermal converter**

I. INTRODUCTION

High-voltage thermal converters (HVTCs) are used as standards of ac-dc difference and for the measurement and calibration of ac voltage up to 1000 V and 100 kHz [1]. A build-up or scaling procedure is generally employed to determine the ac-dc differences of these devices. In the build-up process (shown in Fig. 1) the ac-dc difference of an HVTC is determined by comparison against a thermal converter of a lower voltage rating. Assuming that the ac-dc difference of the higher-range HVTC is independent of voltage level, this comparison will provide the ac-dc difference of the higher-range HVTC, to within the measurement uncertainty. However, the ac-dc difference of the multiplying resistors used in HVTCs may vary as a function of input voltage level, creating significant errors in the build-up process. Formal and informal international intercomparisons of HVTCs have revealed variations among the participant laboratories [2,3]. As a result, several National Measurement Institutes (NMIs) are developing calibration procedures that are independent of the build-up process [4-6]. In this paper, we report an independent method for determining the ac-dc differences of an HVTC based on a Binary Inductive Voltage Divider (BIVD) [7].

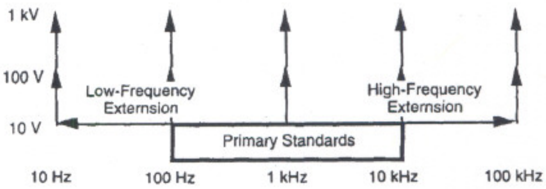

Fig. 1. Build-up diagram for characterizing HVTCs, beginning with the primary standards at 5 V – 10 V and continuing up to 1 kV. The BIVD comparator is intended to address the process indicated by vertical arrows.

II. BIVD COMPARATOR SYSTEM

The comparator system compares the ac-dc differences of two thermal voltage converters (TVCs) to the ratio of a BIVD (although the system is intended for use with HVTCs, in principle TVCs of any voltage ranges may be used, as long as the ranges are roughly 2:1). The comparison requires that the BIVD ratio accuracy and the ratio of two high-voltage dc calibrators be known. The two HVTCs measure the rms

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voltages of two ac calibrators in terms of the dc calibrators. The ratio of the ac calibrators is also determined in terms of the ratio of the BIVD by the use of two high-performance digital voltmeters (DVMs) which are used solely as transfer instruments. The calibration of the DVMs is therefore not required for the measurement process, as the process relies only on the linearity of the voltmeters over a limited voltage range.

A schematic of the comparator system is shown in Fig. 2. A previous prototype of the comparator system [8] featured eight relays spread out across a bench. In the new version of the BIVD comparator system, the eight relays are contained in a shielded enclosure, along with the inductive divider itself, as shown in Fig. 3.

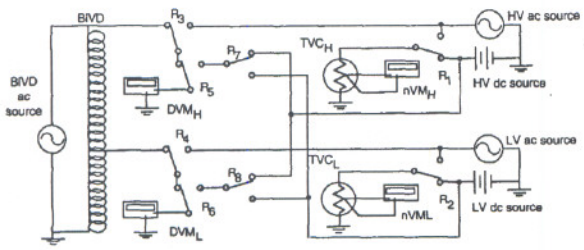

Fig. 2. Schematic of BIVD comparator system.

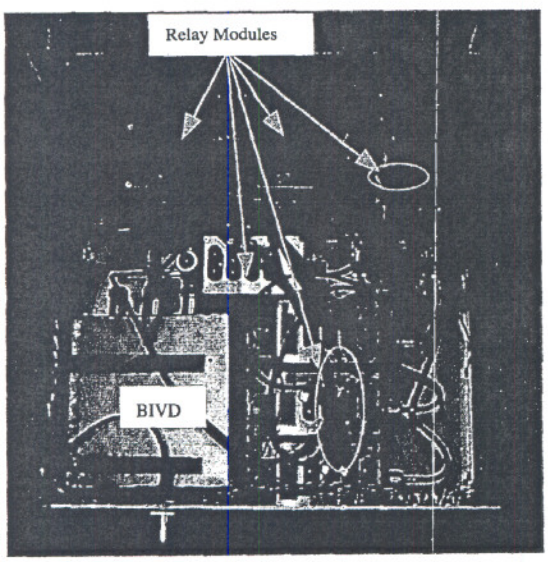

Fig. 3. Interior view of the BIVD enclosure.

The measurement sequence for the BIVD system is described below.

1. The two HVTCs (TVC_H and TVC_L) are connected simultaneously to the high-voltage and low-voltage dc sources while the DVMs are connected to the top of the BIVD (DVM_H) and its center tap (DVM_L). The BIVD voltage is supplied by an ac source. The two HVTC outputs are monitored by nanovoltmeters (nVM_H and nVM_L). The circuit diagram for this phase of the measurement is shown in Fig. 4. Note that all system grounds are actually terminated at the ac source supplying the BIVD.

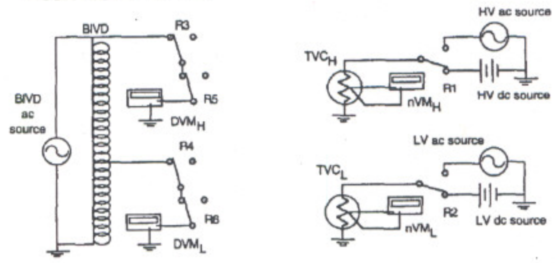

Fig. 4. Circuit diagram of the comparator system while dc voltage is applied to the thermal converters. DVM_H and DVM_L are connected to the BIVD.

2. After the nanovoltmeters and high-voltage DVMs are read, relays R_1, R_2, R_3, and R_4, are switched to their normally-open positions. This supplies ac voltage to the HVTCs, and connects the DVMs to the high- and low-voltage ac sources. In this configuration, the ratios of the high- and low-voltage ac sources are determined in terms of the BIVD center tap ratio. A schematic of this configuration is shown in Fig. 5. While the relays are in these positions, the polarities of the dc voltages are reversed at the sources.

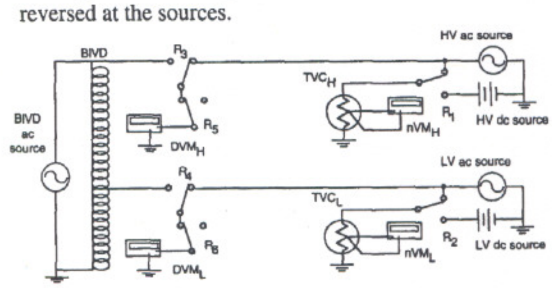

Fig. 5. Circuit diagram of the comparator system while ac voltage is supplied to the thermal converters. DVM_H and DVM_L are also connected to the ac sources.

3. After the nanovoltmeters and high-voltage DVMs are read, relays R_1, R_2, R_3, and R_4, are returned to their normally-closed positions (Fig. 2). The measurement proceeds as in Step 1, except that the dc voltage is of the opposite polarity. Steps 1 and 3 determine the ratio of the ac calibrators in terms of the ratio of the dc calibrators (which are generally more stable), and also (in conjunction with Step 2) determine the ac-dc differences of the two HVTCs.

4. After repeated cycles of the measurements discussed in Steps 1-3, relays R_5 and R_6 are closed to connect both DVMs to the high-voltage dc source, as shown in Fig. 6. DVM readings are taken with both polarities of dc voltage applied to the DVMs. Relays R_7 and R_8 are then closed to connect both DVMs to the low-voltage dc source, and readings are taken with both polarities of dc voltage applied to the DVMs. This procedure determines the departure from nominal ratio of the DVMs.

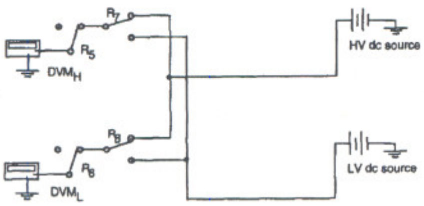

Fig. 6. Circuit Diagram of the comparator system with the DVMs connected to the high-voltage dc sources. When the DVMs are connected to the low-voltage dc source, R_7 and R_8 are in the normally-open position.

Neglecting small second-order quantities, the relationship between the ac-dc differences of the higher-voltage converter and the lower voltage converter, δ_H and δ_L respectively, is:

$$\delta_H - \delta_L = \Delta ratio_{ac} - \Delta ratio_{dc} - \delta_H^m + \delta_L^m$$

where:

δ_H is the ac-dc difference of TVC_H,

δ_L is the ac-dc difference of TVC_L,

$\frac{ac_H}{ac_L} = 2(1+\Delta ratio_{ac})$, $\Delta ratio_{ac}$ is the departure of the ac sources from nominal ratio as determined by the BIVD ratio, in Steps 1, 2, and 3 above,

$\frac{dc_H}{dc_L} = 2(1+\Delta ratio_{dc})$, $\Delta ratio_{dc}$ is the departure of the dc sources from nominal ratio, as determined in Step 4,

$\delta_H^m = \frac{E_{ac} - E_{dc}}{nE_{dc}}$ is the measured result from TVC_H with E_{ac} and E_{dc} the TVC outputs for ac and dc applied, and n the TVC square law characteristic as determined in Steps 1, 2, and 3, above,

$\delta_L^m = \frac{E_{ac} - E_{dc}}{nE_{dc}}$ is the measured result from TVC_L with E_{ac} and E_{dc} the output emf for ac and dc applied, and n the TVC square law characteristic as determined in Steps 1, 2, and 3, above.

III. RESULTS

Table 1 presents data taken with a previous version of the BIVD comparator system compared to the ac-dc differences of several HVTCs predicted from build-up measurements (ac-dc difference data from the new comparator system was not as yet available). In this table, columns 1 and 2 on the left show the results of a direct measurement between a 250 V converter and 500 V converter, and between a 200 V converter and a 500 V converter. Results of the BIVD comparison between these two sets of converters are shown in the right two columns. The uncertainties are the expanded uncertainties for the comparison; the estimated uncertainty for the BIVD is shown in Table 2. As can be seen, the results from the BIVD system compare favorably with those predicted from the build-up. The new BIVD comparator has been designed to address the large Type A uncertainties associated with the BIVD comparator by providing more effective shielding and matching high-voltage lead lengths. Preliminary measurements using the new system indicate that the Type A component of the uncertainty (the dominant term in Table 2) has been reduced to about 2 μV/V; however more measurements are required before the uncertainty can be reduced.

IV. CONCLUSIONS AND FUTURE PLANS

We have demonstrated a comparator system for determining the ac-dc difference of HVTCs independent of the traditional build-up process. Preliminary data show that results from the BIVD comparator are in good agreement with those from the voltage buildup. Future plans include improvements to reduce the Type A component of the uncertainty, and further comparisons against the voltage build-up process using the new BIVD comparator.

V. ACKNOWLEDGMENT

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Table 1. Comparison of results from the BIVD comparator and results from a build-up comparison of NIST HVTCs. The voltage applied at the top of the BIVD was 400 V. Uncertainties are k=2.

Ac-dc Differences in µV/V			
Determined from build-up measurements		Determined from BIVD measurements	
FL-500 V	FL-500 V	FL-500 V	FL-500 V
-1.1 (± 5.6)	+0.1 (± 5.6)	-1.0 (±9.0)	-3.0 (±9.0)
FL-250 V	$F_1$200-200 V	FL-250 V	$F_1$200-200 V

Table 2. Preliminary estimate of BIVD uncertainties

Type A Component	4.0
Dc measurement	1.2
BIVD ratio	1.2
Loading	1.2
RSS	4.5
Expanded Uncertainty (k=2)	9.0